Four-dimensional dynamical approach to the multi-modal fission

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In the low energy fission of heavy nuclei, namely actinides and transactinides, it has been demonstrated that there exist more than one deformation paths for fission process. In mass distribution of fission fragments, mass-asymmetric fission is observed on top of the rather broad symmetric fission distribution. The mass-symmetric component decreases as the excitation energy of the compound nucleus increases, and it is expected that the shell correction is the origin of the asymmetric fission. Sometimes, the shape of the mass distribution shows a drastic change with the change of N (neutron number) and of Z (proton number). In the total kinetic energy (TKE) distribution, several components have been observed and it is expected that TKE reflects the compactness of the scission configuration.

The problem of fission modes has been studied theoretically as well [1, 2]. Because of the importance of the shell correction for the appearance of the multi-modal fission, the nuclear energy surface in a multi-dimensional deformation space has been investigated first to obtain static fission paths. Strutinsky fs shell correction method has been used to estimate the shell correction energy. Saddle points are found in the deformation space and the fission paths are defined as valley paths.

Recently, we proposed a dynamical approach to this problem. The multi-dimensional Langevin equation has been applied to the study of fission of highly excited nuclei and succeeded in reproducing the experimental data like pre-scission particle multiplicities and TKE distribution [3]. Importance of the nuclear friction has been stressed in these studies. By including the shell correction energy to the potential energy surface, we proposed to apply this method to the fission of low excitation as well.

By solving the Langevin equation in multi-dimensional deformation space, the compound nucleus finds its way to fission automatically without assuming the valley paths. Langevin trajectories go out of the spherical region through saddle points; each saddle point is selected according to its barrier height automatically. After passing through the saddles, the trajectories go down the nuclear potential energy surface and they reach the scission points. By looking at the shapes at scission points and by tracing the paths, we can easily distinguish the fission modes for each trajectory.

We applied this approach to several systems, like heavy actinides (Fm, Bk) and transactinides (Sg) [4]. We used a three-dimensional deformation space, namely we employed elongation, fragment deformation and mass-asymmetry to describe the nuclear shape. Since we restrict the model space to be three-dimensional, we put a constraint on the deformations of two future fragments; we assume that both fragments have the same deformation. The shell correction energy is calculated with the code TWOCTR [5]. We assume the hydrodynamical inertia mass and the one-body wall-and-window friction. In the study of Sg and Bk, we found a mass-asymmetric fission component together with a mass-symmetric one. We did not find a mass-asymmetric valley in the potential energy surface and concluded that this mass-asymmetric component appears as a result of the multi-dimensional dynamics. In the study of Fm, we found at least three modes: a compact mass-symmetric mode that corresponds to the magic daughter nucleus Sn, a mass-asymmetric component that has the same origin as in the case of Bk and Sg, and an elongated mass-symmetric component. The TKE value obtained in the theoretical study agreed with the experimental systematics well [6]. However, in these studies, we could not reproduce the experimental fractions of the mass-symmetric and mass-asymmetric components.

In the present paper, we extend the model space to four-dimensional one; we use independent deformation for each fragment. In this way, we can take account of the shell correction more precisely, especially for spherical shells that are strongest. We apply this four-dimensional approach for several heavy-actinides and transactinides.

References

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